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A review of the inflated solar dryer for improving the quality of agricultural product

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A review of the inflated solar dryer for improving the quality of agricultural product

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Abstract. Drying is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. This processing technique can be used to preserve agricultural products. Insufficient drying techniques may result in a progressively worse standard of the product. A number of different sources of energy are commonly utilized in drying processes such as fuel or biomass. The shortage of fossil fuels and expensive processes may damage the environment; consequently, solar-energy-utilized dryers become the main choice for drying agricultural crops. The inflated solar-energy-utilized dryers were used to dry agricultural crops because the design was simple and easy to operate and maintain, and the dryers prevented excessive heat on the top layer of the exposed object to the sun's rays. In addition, they could be installed in new locations in a very short time. This study aimed to review in depth the inflated solar-energy-utilized dryers and found out their advantages. What's more, it paid particular attention to providing a comprehensive description of the design of inflated solar-energy-utilized dryers and their application to a variety of different agricultural commodities. The results of the study showed that the inflated solar-energy-utilized dryers were both faster for drying and improved the product quality regarding the aflatoxin level and impurities.

Keywords: agriculture quality, innovative solar drying, inflated solar dryer

1. Introduction

Solar energy from the sun is very suitable to dry various agricultural products because germination and growth of fungi and bacteria can be prevented. In addition, drying can also preserve agricultural products without causing environmental damage and society[1]. The drying process using solar energy consists of two methods: experimental conditions of a group of open sun drying and controlled group of open sun drying with solar-energy-utilized dryers [2]. The first method of drying process refers to the one that has been widely used in the post-harvest processing of agricultural products which are abundant, renewable, and sustainable[3]. The materials dried by the open sun drying are dispersed on a thin layer of heavy-duty waterproof cloth on the ground, floor, or trays. However, this traditional method has many shortcomings, for example, it needs a large open space, the process is time-consuming[4-5], it cannot be carried out in the rainy season or when sudden rainfall occurs[6], and it yields poor quality product because the drying temperature cannot be controlled and also can be contaminated by the animals and the dust[7-8].

To avoid the previously mentioned deficiencies, an efficient and effective drying system had to be utilized. One alternative dryer of the open sun drying method with low cost and friendly to the environment is a solar-energy-utilized dryer[1]. Solar drying is an efficient drying process taking an initial cash investment of 0.54 - 4.69 years. It mitigates carbon dioxide emissions into the atmosphere by 34% with less fossil fuel consumption[9]. Increasing environmental concern is driving the use of clean and green energy sources to dry various agricultural products [1]. In addition to being friendly to the environment, the use of solar dryers also reduces drying time and does not decrease the nutritional value of dried products especially not changing their taste and color[10]. Solar dryers are very suitable for locations that receive good sun shines during the harvest season[1].

Solar dryers are broadly classified as tray or direct-type dryers, greenhouse dryers, tunnel-type solar dryers, indirect-type solar dryers, mixed solar dryers, and hybrid solar dryers[2]. Several types of solar dryers have been used over the last decades for different agricultural products like cabinet solar dryers for vegetables and fruit drying applications [11], green-house dryers for chili[10], and hybrid solar dryers for coffee[12]. Agricultural dried products can be performed by types and modifications of solar dryers. The selection of the type of solar dryer depends on the requirement, for example, the processing method and its effect on the physicochemical properties of the product, energy consumption, socio-economic aspects[13], and the impact on the environment[14].

One of the alternative dryers with energy efficiency, a cost-benefit ratio, and affability to the environment is an inflated solar dryer[15]. The dryer has been widely used to desiccate a variety of products of grain, corn, oyster mushrooms, and chili[15–20]. Inflated solar-energy-utilized dryers are used to dry agricultural products with their unique features such as being simple in design, easily transportable, and low maintenance compared to mechanical dryers. They can be installed in new locations in a very short time and prevent excessive heat from the top-layer objects exposed to sun rays [6]. The inflated solar-energy-utilized dryer provides an opportunity to increase the quality of the product because it inactivates mycotoxigenic fungi, enteric bacteria, and browning enzymes[20]. This study aimed to review in depth the features and advantages of an inflated solar dryer. In addition, it paid attention to providing a comprehensive description of the design of inflated solar-energy-utilized dryers and their application to a variety of different agricultural commodities.

2. Different types of solar dryers

Solar-energy-utilized dryers are classified into direct-type, indirect-type, and mixed-mode solar dryers[2][21]. They are also classified according to how the product receives and utilizes heat, namely active and passive solar-energy drying systems [22]. Another type of solar dryer is based on the air circulation method, as natural and forced convection solar dryer[23]. Figure 1 shows a further type of solar dryer.

2.1. Types of direct solar dryer

The principle of direct solar is that a product immediately receives solar radiation (Figure 2). A direct solar dryer uses solar radiation that passes through the glass cover to dry agricultural products. It is classified into open sun drying and cabinet-type solar dryers[21]. This type is very simple in design consisting of a box made of wood with a glass cover and a small hole for air to get in and out (Figure 2). Direct solar dryers are low-cost, less maintenance, and easy to operate and are mainly used by small farmers for drying various products on a small scale[1]. Yet, the products become discolored and cracked on the surface due to being directly exposed to the sun's rays, and cause moisture condensation under the glass cover[24].

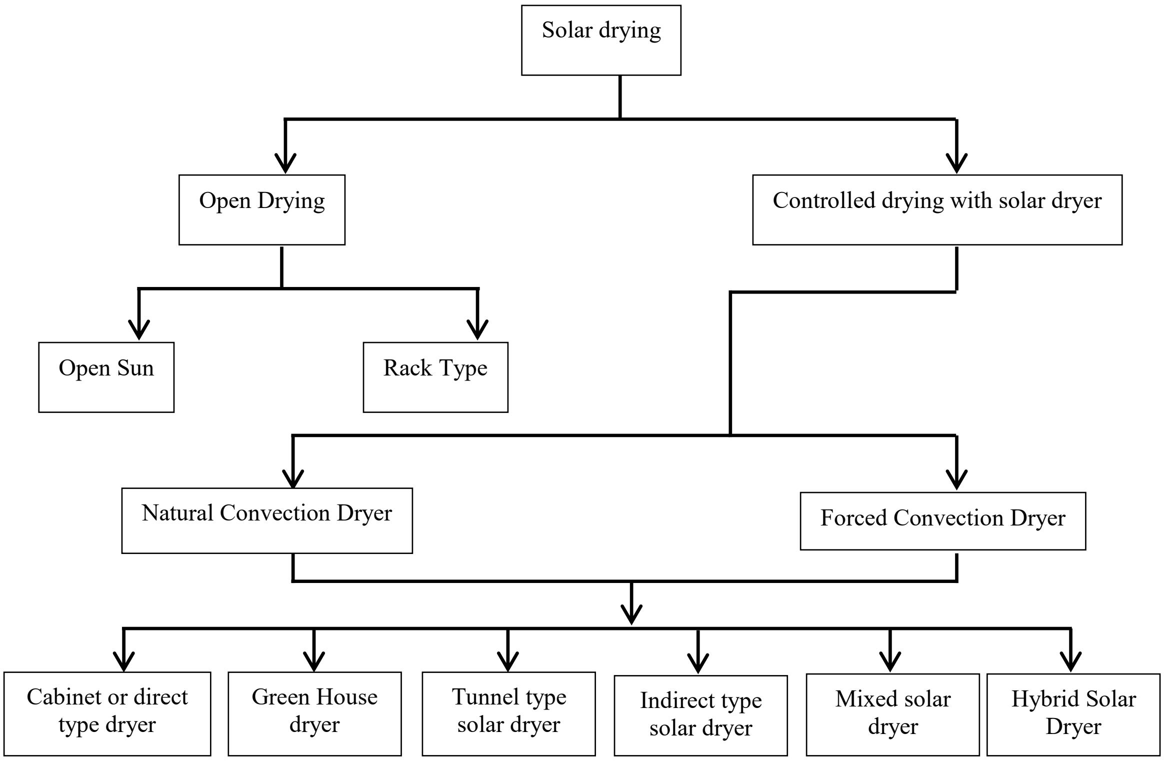

Figure 1. Classification of the solar dryer types

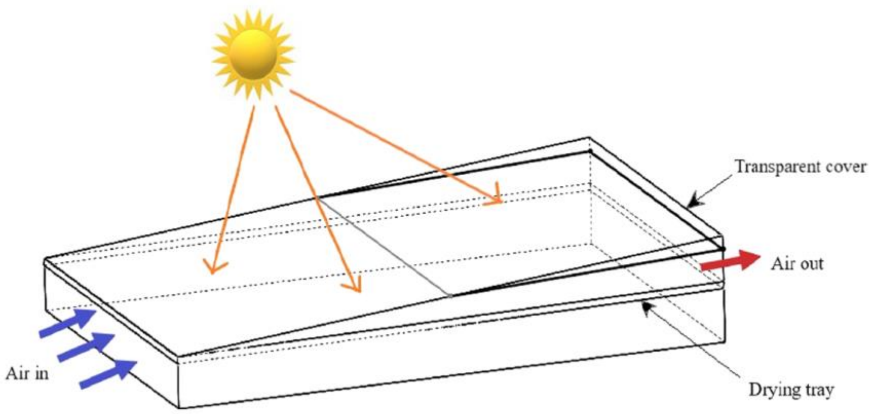

Figure 2. Type of direct solar dryer

2.2. *Type of indirect solar dryers*

The indirect solar dryer is different from the direct one in that an indirect solar dryer has a barrier so that the solar radiation does not hit the product directly. The solar radiation after passing through the cover glass enters the solar collector, the flowing air is thus heated and transferred to the chamber and passes through the product in the drying chamber, and finally exits from the drying cabin through the chimney outlet[21][24]. The indirect solar dryer (Figure 3) consists of two parts, a solar collector for heating air and a drying chamber used to place the product to be dried[25][26]. Solar collectors are needed so that solar energy can be utilized[27] by converting solar radiation into thermal energy[28] and then transferring that heat energy to colder fluids[29]. Solar collectors can be classified as flat plate collectors and concentrating collectors.

Figure 3. Type of indirect solar dryer

The flat plate solar collector (Figure 4) is an insulated box consisting of an absorber, a cover, a heat transfer fluid (air), and an insulated casing[30][31]. The absorber plate is painted black and made of iron or aluminum which functions to absorb the solar energy and then transfer it to the heat transfer fluid and leading to an increase in its temperature[30–32]. The absorber plate is located under a transparent cover made of acrylic[30] or glass[33]. The cover functions to collect heat and reduce heat loss by conduction and convection from the collector[33]. The principle of the flat plate type of solar collector is to accumulate the solar energy that reaches the collector surface. The black plate in the collector absorbs 80% of the solar thermal energy, meanwhile, about 10-35% of the heat is lost on the surface of the collector (Figure 4). The absorbed energy is then transmitted to the heat storage fluid under the absorber plate[29].

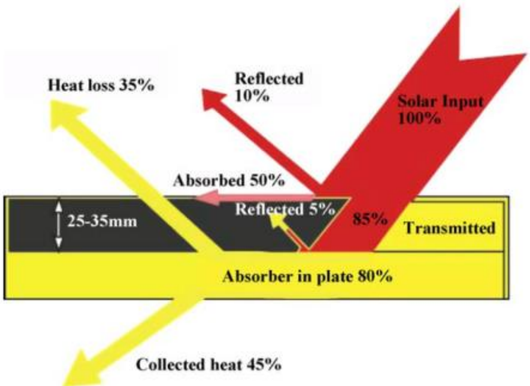

Figure 4. Flat plate collector

2.3. Mixed mode type of solar dryer

A mixed-mode type of solar dryer is one with a combined working principle of the direct and indirect types of solar dryers (Figure 5). The drying process is carried out with hot air and direct sunlight. Just like the indirect type, the inlet air is heated at the solar air collector and flows toward the drying chamber. Additional heat is obtained from the solar radiation that penetrates the drying chamber made from glass[21].

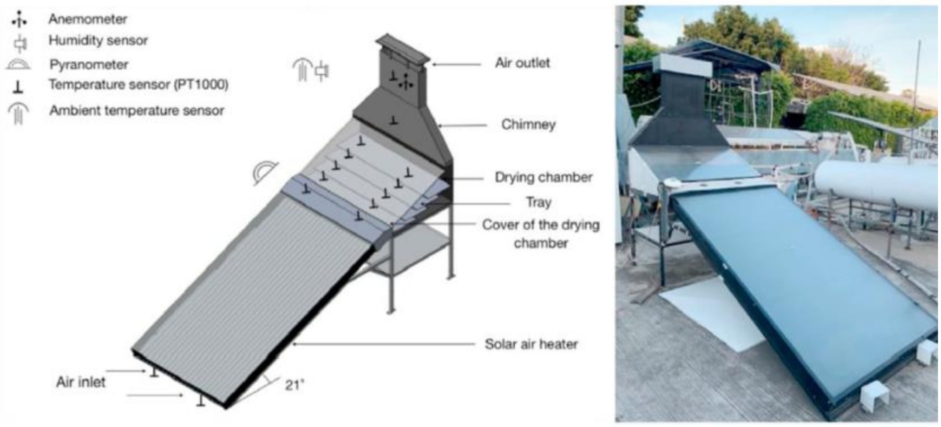

Figure 5. Mixed mode type of solar dryer

3. Features and benefits of the inflated solar dryer for different agricultural products

An inflated solar dryer is a type of solar tunnel dryer, which is the result of a collaboration between Grain Pro Philippines, IRRI and University of Hohenheim in 2015. The tunnel uses no support structure and is sufficiently stabilized by the air pressure from the inflation. This dryer has dimensions of 25 meters long, 2 meters wide, and 1.5 meters high with an upper cover of the inflated solar dryer of transparent LDPE, which is UV and water resistant. The drying floor is made of black PVC water resistant with a thickness of 520 µm. These two plastics are connected by a zipper. The filling of the product sample to be dried is only 23 meters long, while the rest is a heating area to balance the incoming airflow[19][34].

The dryer is equipped with two DC axial fans driven by a battery that is charged by two solar panels[19]. After the product was dried and put into the dryer then the fans were turned on. The air was blown through the ventilator by these fans which inflated the body dryer and provided airflow for drying. When the solar radiation penetrated the transparent top cover, it was trapped in an inflated dryer due to the greenhouse effect[35].

The advantages of the inflated solar dryer are large-scale application, minimizing the effects of unpredictable weather on commodities[34], improving the quality of the dried products because the products are enclosed in a transparent bubble condition, and reducing the drying time of the open sun drying[36]. Another advantage of this type of dryer is the energy to operate the machine was the lowest, but the disadvantages of APGS were investment costs and higher labor requirements compared to any other type[37]. This dryer is extensively used to desiccate a variety of agricultural commodities such as horticulture and grain products.

3.1. Horticulture commodity

The solar dryer is suitable to dry perishable horticultural products with high moisture content. Red chili is an agricultural commodity with high moisture content and is very susceptible to contamination by mycotoxin[38]. Desiccating is a preservation procedure to reduce mycotoxin contents. A low-cost and simple inflated solar dryer has been designed for smallholder chili farmers[20]. In a single layer 5-15 cm deep, the performance of 3.5-ton red chili was evaluated using the inflated solar dryers (Figure 6). These dryers shortened the time drying by more than 50% compared to those using the open sun drying with high quality results, i.e. brighter color of dried chili. It decreased the moisture content from 70-80% to 10-12%. The ambient air temperature ranged from 26 – 35°C and the RH ranged from 45 to 82% with solar radiation intensity varying from 105,000 to 121,000 lux and the solar altitude angle at noon ranged from 78 – 82°C. the chili drying with inflated solar dryer was conducted intermittently. When the temperature reached the peak, the blower turned off for 30-120 minutes. This activity was repeated for 3-5 days until the chili moisture level was reached. The intermittent process intended to maximize the temperature and cause a blanching effect that could inactivate mycotoxigenic fungi, enteric bacteria, and browning enzymes.

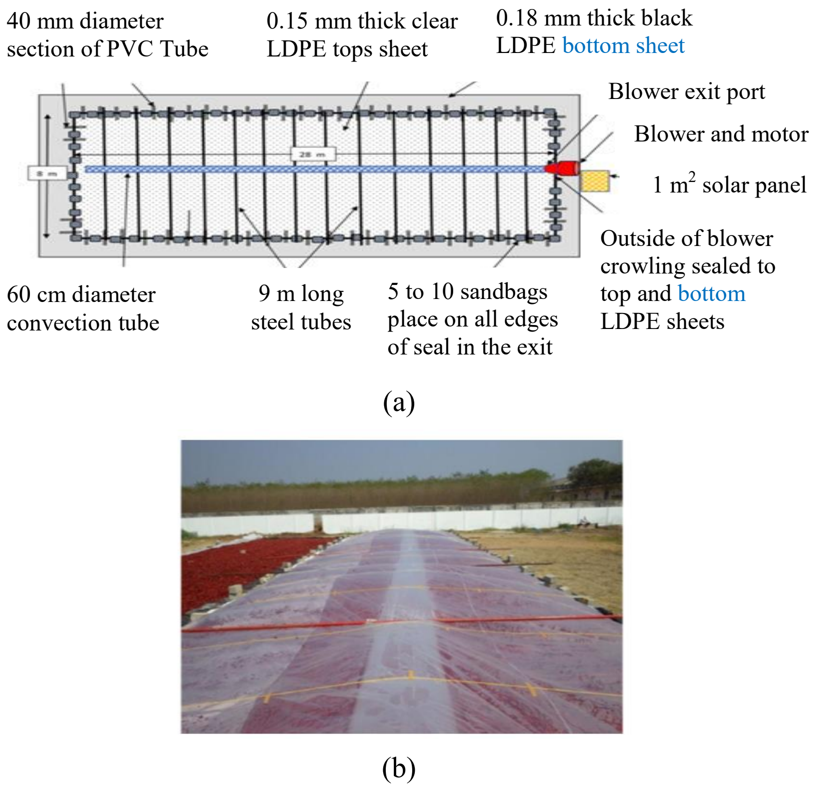

Figure 6. Inflated solar dryers for red chili drying

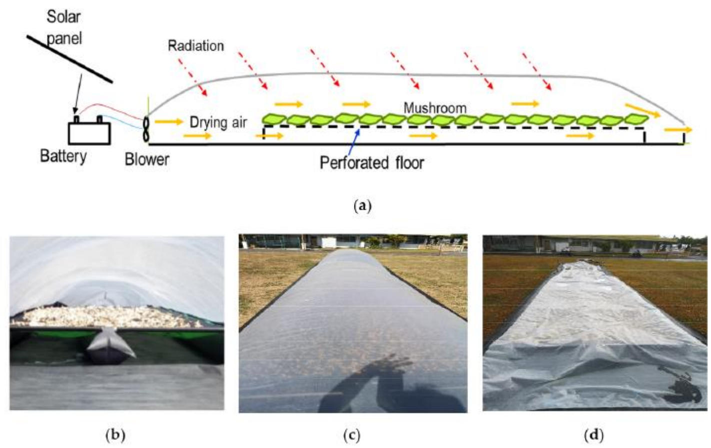

Figure 7. Inflated solar dryers for oyster mushroom drying

Oyster mushrooms are another horticultural commodity that is dried by an inflated solar dryer [15] (Figure 7). The inflated solar dryer has a perforated floor added so that there is no need for mixing or turning mushrooms during drying. The Oyster mushroom was dried within 2-4 h from 90% to 40-60% moisture content at the first step. In the second step, it was dried within 4-6 h from 40-60% to 8-10% moisture content. The mean of the sun's ray vehemence, surrounding heat intensity, and RH in the daylight period were 400-600 wm^{-2}, 28-32°C, and 60-70%, respectively. The inflated solar dryer had the potential to dry oyster mushrooms because it was faster than the open sun drying and did not change the characteristics of the mushrooms. Drying the oyster mushrooms with an inflated solar dryer did not cause the mushroom to decay and their coloration was still white-cream. It is also economically feasible because the net profit is 20% higher than the investment cost per year with a length of investment time reaching a breakeven point of four years.

3.2. Grains and bean commodity

Research and investigation of the desiccating of rice utilizing a solar inflated dryer were already carried out[35]. The inflated solar dryer has two waterproof plastic films, namely, a lower cover using black polyvinyl chloride (PVC) and an upper cover using transparent UV-resistant of low-density polyethylene (LDPE) (Figure 8). The black lower cover absorbs efficiently the sunlight pre-heating the drying air[39]. The temperature in the inflated solar dryer was higher by 10 to 13°C than the surrounding heat intensity. The mean of the sun's ray vehemence and temperature in an inflated solar dryer was 580-788 wm^{-2} and 47-60°c, respectively. It took 8 h to remove the moisture level from 15.6% to 13%. The obtained good quality of paddy rice showed that, particularly, the level of impurities of rice was lower than the one in the open sun drying.

An inflated solar dryer (Figure 9) is also used in Bangladesh to dry rough rice[16]. The dryer was equipped with a solar collector to change the energy derived from the sun's rays into heat getting inside the inflated solar dryer has two solar panels, a rechargeable battery, a controller, axial flow ventilators and a simple roller for the admixture of the grains (Figure 10). The axial fan blew the air into the inflated solar dryer through two vents on the opposite side. The ventilators were still operated during the experimental trial and at night time in order to keep the dryer inflated[39].

The inflated solar dryer took 16 to 20 h to remove the moisture level of rice from 26% to 13%. The result was slightly different from the research conducted[39]. It took 26-52 h to decrease the moisture level from 26% to 13% during the rainy season and 4-26 h to decrease the condensation level from 16% to 14% in the dry season. Regarding the quality, the open sun dryer had a low degree of hardness of rice, higher seed germination rate[35] and high quality head rice yield[39]. Table 1 presents the performance parameters of the inflated solar dryer.

Figure 8. Inflated solar dryers for the paddy rice drying

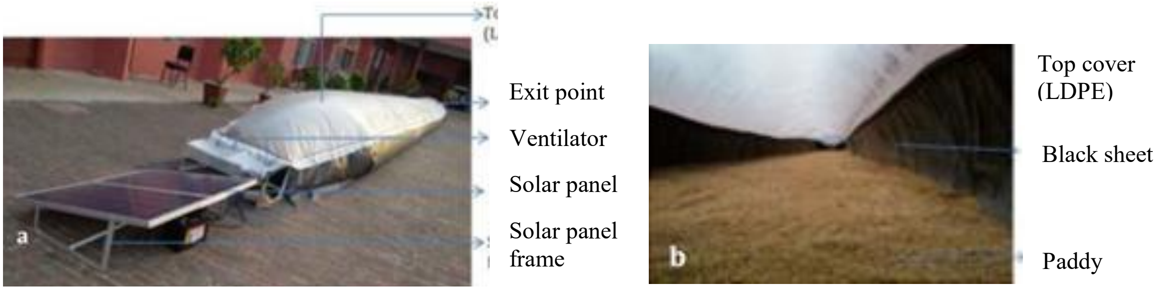

Figure 9. Inflated solar dryers for rough rice drying in Bangladesh

Figure 10. Roller for the admixture of the grains

Table 1. Drying and performance parameters of inflated solar dryer

Commodity	MC (wb%)		Drying time	Average solar intensity	Ambient temperature	RH (%)
	MC_{in}	MC_{out}	(h)	(Wm^{-2})	(°C)	
Red chili[20]	70-80	10-12				
Oyster mushrooms[15]	90	10	10	400-600	28-32	60-70
Paddy rice[35]	15.6	13	8	580-788		
Rough rice[16]	26	13	20			
Maize grain[34]	29	13	24	450-1.126.	18.5-33	35-78
Coffee[40]	40.5	12	27		31-46	
Corn[40]	38.9	13	14		31-51	
Maize[18]	23.5	11.9	19			28
Amaranth Leaves[41]	80	11.6	68.08	510-950	30	97.4

Conclusion

Inflated solar dryer has the potential to be adopted by farmers to improve the quality of agricultural products. The advantages of an inflated solar dryer are effective and efficient so it is highly recommended for use by farmers with limited drying facilities.

References

[1] Chauhan Y B and Rathod P P 2020 *Int. J. Ambient Energy* **41** 3 348–67
[2] Lingayat A B, Chandramohan V P, Raju V R K and Meda V 2020 *Appl. Energy* **258** 114005
[3] Azaizia Z, Kooli S, Elkhadraoui A, Hamdi I and Guizani A A 2017 *Int. J. Hydrogen Energy* **42** 13 8818–26
[4] EL khadraoui A, Hamdi I, Kooli S and Guizani A 2019 *Innov. Food. Sci. Emerg. Technol.* **52** 262–70
[5] Rabha D K and Muthukumar P 2017 *Sol. Energy* **149** 214–26
[6] Salvatierra-Rojas A, Ramaj I, Romuli S and Müller J 2021 *Appl. Sci.* **11** 7
[7] Akmak G and Yildiz C 2011 *Food Bioprod. Process* **89** 2 103–8
[8] Labed A, Moummi N, Aoues K and Benchabane A 2016 *J. Clean Prod.* **112** 2545–52
[9] Kamarulzaman A, Hasanuzzaman M and Rahim N A 2021 *Sol. Energy* **221** 559–82
[10] Nukulwar M R and Tungikar V B 2021 *Mater. Today Proc.* **46** 345–9
[11] Islam M, Islam M I, Tusar M and Limon A H 2019 *Elsevier Enhanced Reader* p. 769–76
[12] Yuwana Y, Silvia E N and Sidebang B 2021 Proc. Int. Semin. Promot. Local Resour Sustain. Agric. Dev. **13** 497–503.
[13] Mohana Y, Mohanapriya R, Anukiruthika T, Yoha K S, Moses J A and Anandharamakrishnan C 2020 *Sol. Energy* **208** 321–44
[14] Singh P and Gaur M K 2021 *Sustain. Energy Technol. Assessments* **47** 101428
[15] van Hung N, Fuertes L A, Balingbing C, Roxas A P, Tala M and Gummert M 2020 *Energies* **13** 6
[16] Alam M A, Saha C K, Alam M M, Manir M R, Hasan M and Rashid M M 2020 *J. Biosci. Agric. Res.* **23** 2 1920–30
[17] Maryana Y E, Suprihatin A, Amirullah J and Yustisia 2021 *J. Pengkaj. dan Pengemb. Teknol. Pertan.* **24** 3 319–29
[18] Ntwali J, Schock S, Romuli S, Kiria Chege C G, Banadda N, Aseru G, et al 2021 *Appl. Sci.* **11** 15
[19] Romuli S, Schock S, Nagle M, Chege C G K and Müller 2019 *J. Appl. Sci.* **9** 16
[20] Watson A G, Aleckovic S and Nallamothu R 2022 *Dry Technol.* **40** 11 2274–82
[21] Kumar P and Singh D 2020 *Renew. Energy Focus* **35** 148–58
[22] Tiwari A 2016 J Food Process Technol **7** 9
[23] Vijayan S, Arjunan T V and Kumar A 2016 *Innov. Food Sci. Emerg. Technol.* **36** 59–67
[24] Sharma A, Chen C R and Vu Lan N 2009 *Renew. Sustain. Energy Rev.*.;**13** 6–7 1185–210.
[25] El Khadraoui A, Bouadila S, Kooli S, Farhat A and Guizani A 2017 *J. Clean. Prod.* **148** 37–48
[26] Pangavhane D R and Sawhney R L 2002 *Energy Convers. Manag.* **43** 1 45–61
[27] Yadav A and Bajpai V K 2011 *World. Acad. Sci. Eng. Technol.* **79** 7 81–6
[28] Kumar A, Tiwari A K and Said Z 2021 *Sustain. Energy Technol. Assessments* **47** 101417
[29] Hossain M S, Saidur R, Fayaz H, Rahim N A, Islam M R, Ahamed J U, et al 2011 *Renew. Sustain. Energy Rev.* **15** 8 3801–12
[30] Irwansyah 2019 *J. Keteknikan Pertan.* **7** 3 163–70
[31] Lamrani B and Draoui A 2021 *Dry Technol.* **39** 10 1371–88
[32] Syah H, Agustina R and Moulana R 2016 *Rona Tek. Pertan.* **9** 1 25–39
[33] Saban R, Sukmawaty, Murad, Ansar and Amuddin 2021 *Proceeding ICST* p. 1–9
[34] Asemu A M, Habtu N G, Delele M A, Subramanyam B and Alavi S 2020 *J. Food Process. Eng.* **43** 2 1–19
[35] Romuli S, Schock S, Somda M K and Müller 2020 *J. Appl. Sci.* **10** 10
[36] Armah K A, Akowuah J O, Obeng-Akrofi G and McNeill S G 2021 *J. Appl. Sci.* **11** 01 157–75
[37] Nguyen-Van-Hung, Tran-Van-Tuan, Meas P, Tado C J M, Kyaw M A and Gummert M 2019 *Plant Prod. Sci.* **22** 1 107–18
[38] Costa J, Rodríguez R, Garcia-Cela E, Medina A, Magan N, Lima N, et al 2019 *Toxins* (Basel) **11** 27

[39] Salvatierra-Rojas A, Nagle M, Gummert M, de Bruin T and Müller J 2017 *Int. J. Agric. Biol. Eng.* **10** 3 269–82.
[40] Oria C L and Palconit E V 2022 *Eng. Technol. Appl. Sci. Res.* **12** 3 8707–11
[41] Romuli S, Schock S, Nagle M, Kiria Chege C G and Muller 2019 *J. Appl. Sci.* **9** 3431 2–11